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The radar cross sections (RCS) of a goose and two ducks were measured at a frequency of about 1166 MHz. The birds were placed in a polyfoam cage that was rotated in azimuth in 5-deg steps. The measurements were made with both vertical and horizontal polarizations. Radar cross sections of the duck varied between 0.048 m^2 and 0.02 m^2 for horizontal polarization, and between 0.02 m^2 and 0.001 m^2 for vertical polarization. Radar cross sections of the goose varied between 0.28 m^2 and 0.07 m^2 for horizontal polarization,

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and between 0.18 m^2 and 0.0017 m^2 for vertical polarization. The measured data have been presented in several ways so that trends and characteristics can be observed.

Preface

The authors are pleased to acknowledge the assistance of Mr. Gerald Preston who aided in the assembly of the equipment and with taking of the data, as well as with maintenance of the scattering models.

Contents

Illustrations

Tables

Measured L-Band Radar Cross Sections of Ducks and Geese

1. INTRODUCTION

Considerable attention has been paid to radar scattering by birds,[1, 2, 3] but literature searches reveal essentially no measured data at L-Band which is a popular operating frequency for ground based radars. The measurements to be described in the present report were undertaken to fill this void and especially to supply data on the radar cross sections of larger birds. Their dimensions are near the upper end of the resonant region of electromagnetic scattering at L-Band and hence may be expected to show substantial radar cross sections.

Measurements at a frequency of about 1165 MHz were carried out on a conventional backscatter range of three full-grown, farm raised birds. Two were ducks of nearly the same weight, 1.834 kg and 1.868 kg, respectively, corresponding to 4.04 and 4.11 lb. The birds measured 17 in. around the largest part of the body; the body measured 16 in., with neck and head 8 in. The third was a goose of approximately 4.910 kg or 10.8 lb.

(Received for publication 29 March 1979)

1. Pollon, G.E. (1972) Distribution of radar angels, IEEE Trans. AES:701-727, AES-8.
2. Edwards, J. and Houghton, E.W. (1959) Radar echoing area polar diagrams of birds, Nature 104:1059.
3. Blacksmith, P. and Mack, R.B. (1965) On measuring the radar cross sections of ducks and chickens, Proc. IEEE 53:1125.

Radar cross sections of more than 0.25 m^2 were measured with the goose at horizontal polarization and of more than 0.04 m^2 with the duck at horizontal polarization. In each case, their necks were somewhat retracted so that in actual flight attitude when their necks are extended, larger cross sections might be expected at horizontal polarization. With vertical polarization, maximum cross sections of about 0.18 m^2 were observed from the goose and about 0.02 m^2 from the ducks.

For measurements, the birds were placed in polyfoam cages that in turn could be rapidly positioned at the top of a polyfoam column to permit measurements under simulated free space conditions. Point by point measurements were made at 5-deg intervals for azimuth orientations of the birds from head-on, through broadside, to tail-on. This point by point method was chosen because the birds tend to move erratically if the mount is continuously rotated.

The attitude of the birds during the measurements only approximated actual bird attitude in flight. The most notable differences are that the wings were always folded against their body and the ducks tended to sit in the cage with their neck retracted rather than extended as in flight. Some measurements were obtained with the goose when his neck was extended approximately 2/3 of its length; differences in the radar cross section between this extended and nearly fully retracted position of the neck are significant and noted in the data. The closest correlation between these measured results and those observed under actual flight conditions would occur when the electric field of the radar beam is normal to the longitudinal axis of the bird.

2. MEASUREMENT EQUIPMENT AND RANGE

A conventional balanced tee backscatter equipment using a single antenna for transmitting and receiving[4] was assembled to use on an outdoor range for the measurements. A block diagram of the equipment is shown in Figure 1; Figure 2 is a photograph of the assembly. All components were commercially available items.

With this type of a backscatter measurement system, the smallest cross sections that can be measured accurately are determined by the ability to cancel background signals and to maintain the cancelled level during the time required to complete an individual measurement. Principal factors limiting this ability are sensitivity of the equipment assembly to vibration and to temperature changes, the

4. Blacksmith, P., Hiatt, R.E., and Mack, R.B. (1965) Introduction to radar cross section measurements, Proc. IEEE 53:902-920.

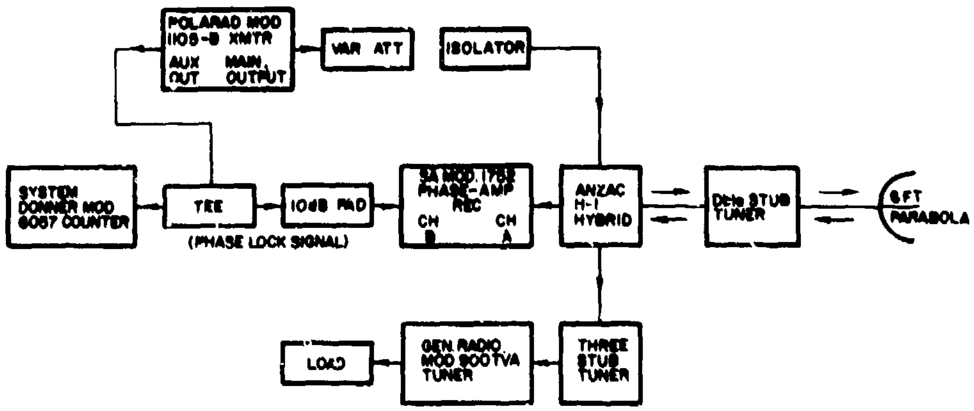


Figure 1. L-Band Backscatter Measurement System

degree of fine adjustment available in the tuning stubs, and the short term stability of the signal source.

The sensitivity of the assembly to vibration was significantly reduced by fastening solidly all components, including all flexible coaxial cables, to a sheet of 5/8 in. plywood. Individual wooden braces were fitted to provide support and relieve strain of adjoining components. It was particularly important for flexible cables to be supported within a few inches of their connectors. Type N connectors were used wherever possible because they are relatively free from vibration problems and the larger heavier cables tend to flex less than small ones. In addition, all rf connections were wrapped tightly with several layers of conducting aluminum tape, both to add support and to reduce leakage signals. Some of the supporting braces and clamps along with the sealed connections can be seen in Figure 2.

In Figure 2, the vertical double stub tuner was used to reduce the VSWR of the transmit-receive antenna; it was attached to the output arm of the hybrid. The horizontal triple stub tuner was adjusted to obtain all but the final 10 dB to 20 dB of background signal cancellation. Final adjustments were carried out with a General Radio Model 900 TVA triple screw tuner.

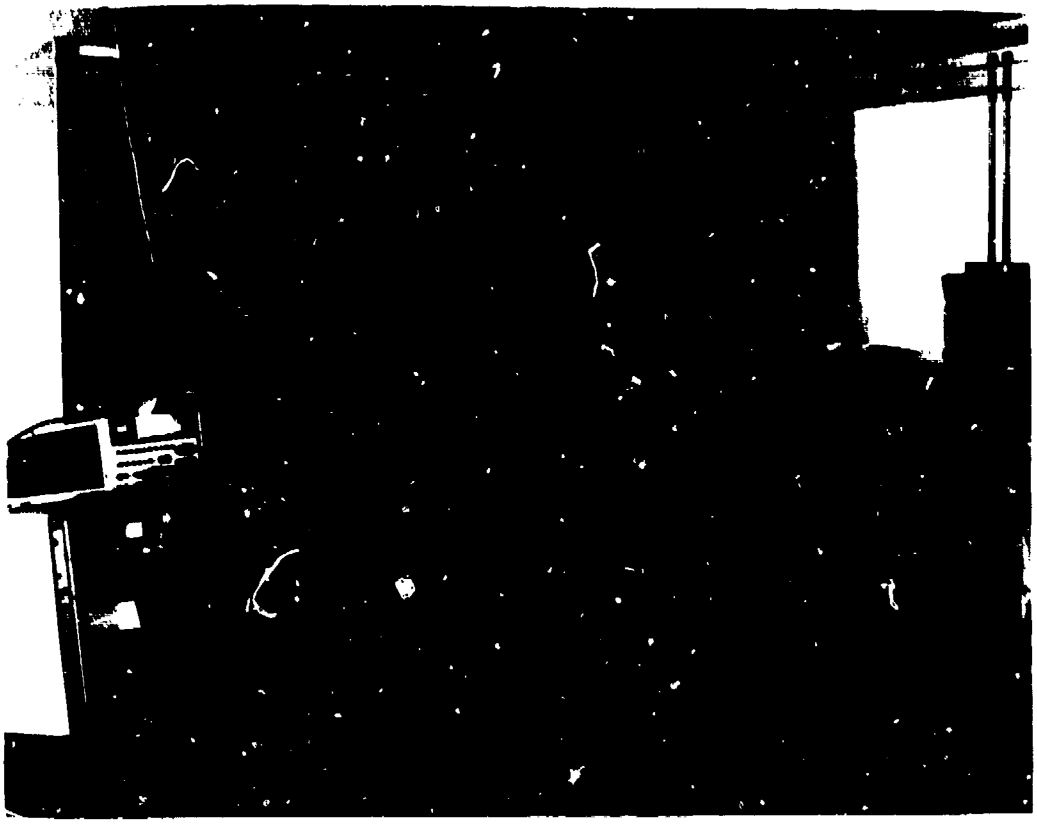


Figure 2. Measurement Equipment

As can also be seen from Figure 2, the matching units and hybrid tee were wrapped insofar as possible in a foamed packing material to reduce their temperature sensitivity. No additional temperature control was provided in the room housing the equipment, and the transmit-receive antenna was mounted out of doors.

The transmit-rece've antenna was a 6-ft paraboloidal reflector with a dipole feed, and this feed proved to be one of the most temperature-sensitive components in the assembly when it was exposed to the continual heating and cooling effects of the sun. The resulting contractions and expansions appeared to cause changes in the antenna VSWR that, even though small, were still enough to cause rapid changes in the small balanced background signals at the hybrid. These disturbing effects were significantly reduced by enclosing the feed in several inches of insulating material.

The transmit-receive antenna was rigidly mounted against the building with its center approximately 6 ft above a wooden platform. During measurements, the polyfoam bird cages were placed on top of a polyfoam column of approximately 12 in. to 14 in. diameter and 33 in. height, and the column in turn was attached to a wooden base as shown in Figure 3. The polyfoam cages and column are shown in Figure 4. Approximate dimensions of the cages are given in Table 1.

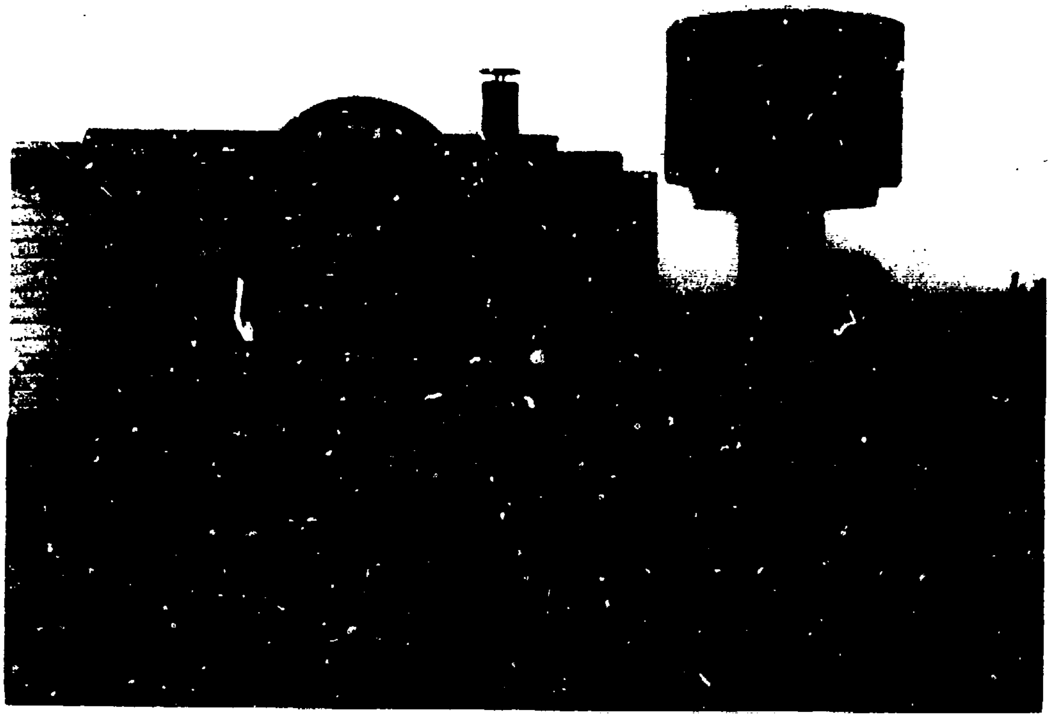
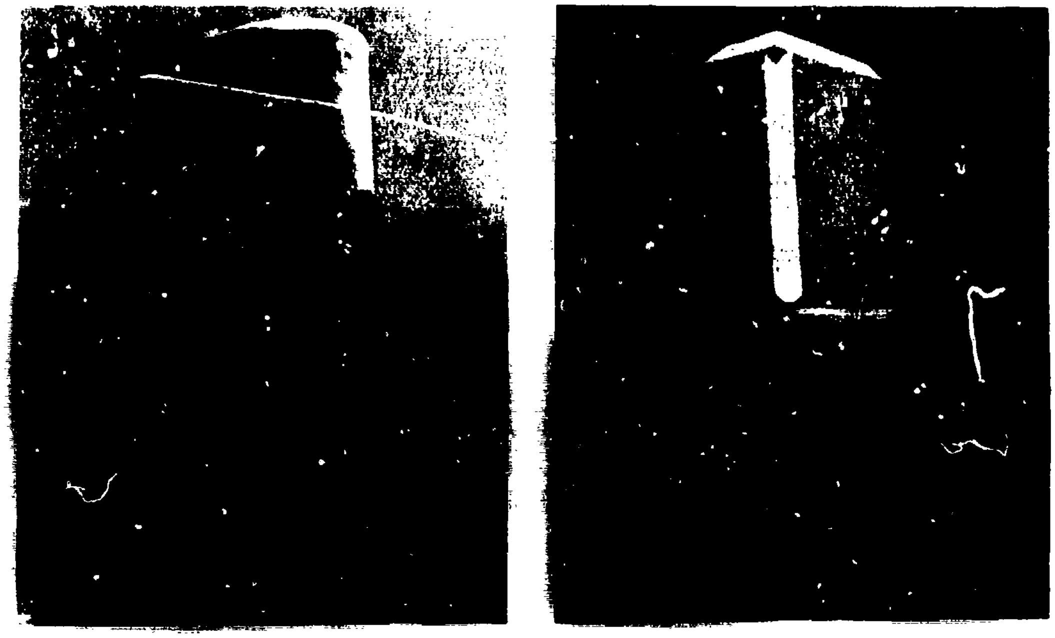


Figure 3. Measurement Range

Table 1. Polyfoam Cage Dimensions

	Goose Cage		Duck Cage	
Dimension	Outside	Inside	Outside	Inside
Height	31"	22"	16"	8"
Width	21"	17"	22"	18"
Depth	14"	10"	15"	8"



a. Duck b. Goose

Figure 4. Polyfoam Bird Cage

The actual far field of the 6-ft parabola is

$$R = \frac{2D^2}{\lambda} = 84 \text{ ft} \tag{1}$$

where D is the maximum aperture of the antenna and λ is the wavelength. However, probing of the aperture fields has shown[5, 6] that nothing dramatic happens at distances as short as $D^2/2\lambda$, as short as or about 21 ft for the combination of interest here. Assuming a maximum dimension of 3 ft for the birds, their far field from Eq. (1) would be about 21.2 ft In order to minimize the $1/R^4$ propagation losses, a distance of 22 ft was chosen between the model mount and the transmit-receive antenna, thus permitting measurements well into the far field of the largest bird while maintaining smooth incident fields over the target space. This distance had the additional advantage of placing the wooden mount base very near a null of the antenna pattern so that backscatter from the base was negligible and did not require absorber shields for reduction.

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5. Mack, R.B., Wojcicki, A.W., and Andriotakis, J.J. (1973) An Implementation of Conventional Methods of Measuring the Amplitude and Phase of Backscatter Fields, AFCRL-TR-73-0418, AD A770015, RADC/EE, Hanscom AFB, MA.
6. Sommerfeld, A. (1964) Optics, p. 217, Academic Press, New York.

The incident electric field over the target space was checked at both horizontal and vertical polarization by moving a 4-in.-diam sphere in approximately uniform steps through the beam. The field variation is given by one half the recorded power variations in dB, with corrections for the $1/R^4$ variation. These results are graphed in Figures 5 and 6. In each case, a working region of approximately 3 ft can be found over which the incident field variation is approximately ±0.5 dB.

The Poloroid Model 1105-B signal generator, operated without additional frequency stabilization, proved to be sufficiently stable so that it was not a limiting factor in the measurement times. An output of approximately 20 mW from the Model 1105-B resulted in 5 to 6 mW transmitting power at the antenna input. With these levels of transmitted power, an 8-in. sphere produced returns of -40 dB to -45 dB on the Scientific Atlanta Model 1752 receiver with the latter adjusted for convenient operating levels. Background signals were cancelled to -75 dB to -80 dB levels, resulting in a dynamic working range of 35 dB to 40 dB. With good weather conditions, cancellation levels of -65 to -70 dB lasted for minutes. Approximately 20 to 30 sec were required for each individual measurement.

Generally, the criteria used to consider a measurement valid was that the background signal at the completion of a measurement should be at least 20 dB below the target signal. For a few orientations of the birds that consistently showed low cross sections, this criterion was relaxed to -15 dB, and in a very few instances near a null in the scattering pattern, to -10 dB. Uncertainties in the measured results due to these levels of background signals[4] are given in Table 2. Thus, from Table 2, nearly all of the measured results have range errors of ±1 dB or less, with this increasing to ±3 dB at angles corresponding to low levels of scattering.

Table 2. Errors in Measured RCS Due to Background Signals

Target Signal Level Minus Background Signal Level	Measurement Uncertainty
30 dB	±0.3 dB
20	±1.0
15	±1.6
10	±3.2

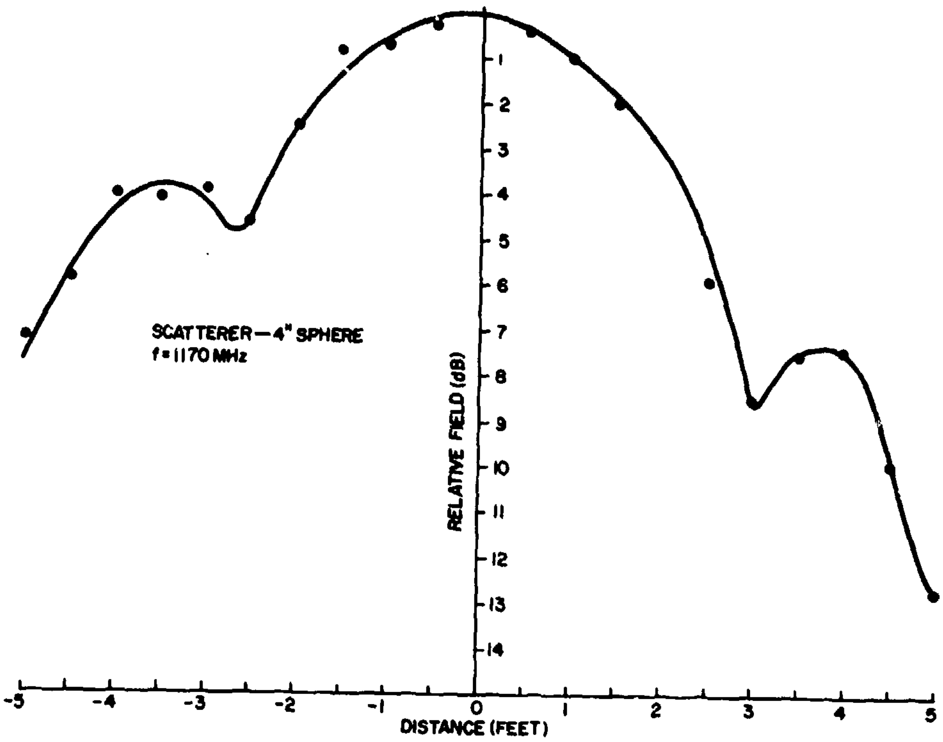

Figure 5. Horizontal E-Field (Horizontal Polarization)

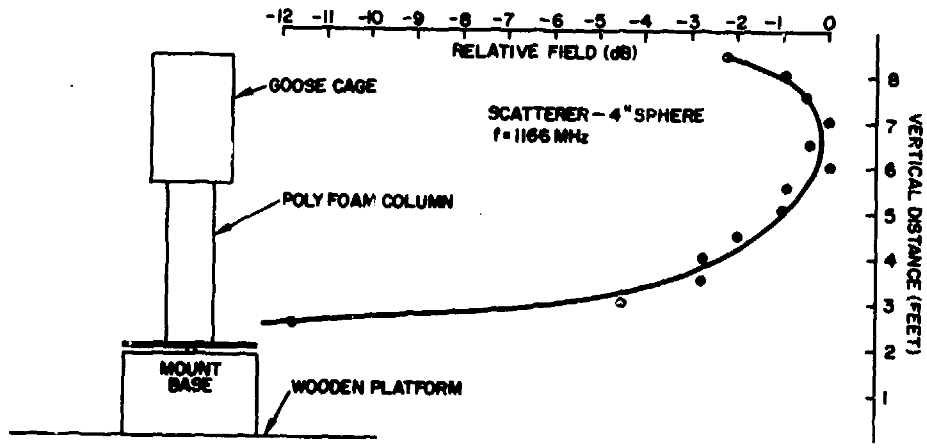

Figure 6. Vertical E-Field (Vertical Polarization)

Several experiments were carried out to determine any measurable effects of the polyfoam cages alone. Direct measurements of the cross sections of the cages showed them to be 25 to 35 dB below that of the 8-in. sphere. An 8-in. sphere in the duck cage showed variation of ±0.5 dB when the cage and sphere together were rotated throughout the angular intervals to be used for the bird measurements. Finally, sets of metal spheres of different sizes were measured in the cages and the ratios of their measured cross sections were compared with corresponding calculated results. The measured ratios for all but those involving the 4-in. sphere, the smallest used, were within ±0.5 to 0.75 dB of the calculated ones. As long as the 4-in. sphere was raised several inches above the bottom of the cages, its results also agreed with calculated ones. When the 4-in. sphere was located on the bottom of the cages, a significant portion of its volume fell into a region of reduced incident field and differences between measured and calculated results were consistent with this effect.

Based on the above tests, it was concluded that the cages had no significant effects except at the relatively low cross sections, and then their effects would be of the same order as those due to the tolerated unbalance of the hydrid at the conclusion of each measurement.

3. MEASURED RADAR CROSS SECTIONS

The measured radar cross sections as functions of azimuth orientation from head-on through tail-on directions are given in Figures 7 to 9 for the ducks and in Figures 10 and 11 for the goose. In those figures, the bottom scale is the azimuth angle in degrees; the vertical scale at the left side is the radar cross in square meters, and the vertical scale at the right gives the relative cross section in dB referred to 1 m^2.

Calibrations for the data in Figures 7 to 11 were obtained in the conventional manner, by comparing the power level of the receiver due to reflections from the bird at a given attitude and polarization with the power level of an 8-in.-diam metal sphere. Then,

$$\Delta dB = \sigma_{dB\,B} - \sigma_{dB\,S} = 10 \log \frac{\sigma_B}{\sigma_S}$$

and (2)

$$\sigma_B = \sigma_S \log^{-1}(\Delta dB/10) \quad ,$$

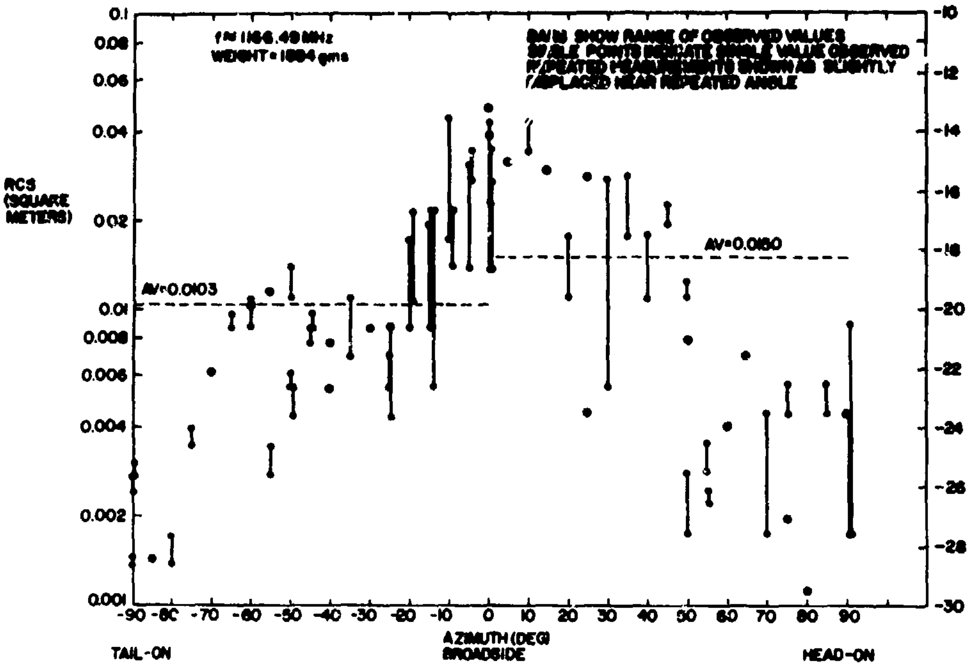

Figure 7. Measured Radar Cross Section—Duck No. 1, Horizontal Polarization

where $\sigma_{dB\,B}$ is the relative cross section of the bird in dB, σ_B is the absolute cross section of the bird, $\sigma_{dB\,S}$ is the relative cross section of the sphere, and σ_s is the absolute cross section of the sphere. With a frequency of approximately 1166 MHz, the wavelength was $\lambda = 10.172$ in. and circumference of the sphere in wavelength was 2.47λ, $ka = 2\pi a/\lambda = 2.4836$. From[7], $\sigma_s/\pi a^2 = 1.764$ and $\sigma_s = 0.0572\ m^2$. The frequency varied slightly for each set of measurements and the corresponding values of σ_s were recalculated from[7], but differences are small within the range of frequency variation. For example, for frequencies between 1163 MHz and 1168 MHz the radar cross section of the 8-in. sphere changes only from $0.0578\ m^2$ to $0.0568\ m^2$.

Unlike the usual inanimate models, birds do not remain perfectly stationary when placed on the mount. Their movement results generally in the observation of a range of values instead of a single value at each measurement. The range of values observed at each measurement is shown by a vertical bar in Figures 7 to 11. When only a single value was observed, that value is shown as a circled point. Measurements were made at regular multiples of 5-deg azimuth angular intervals.

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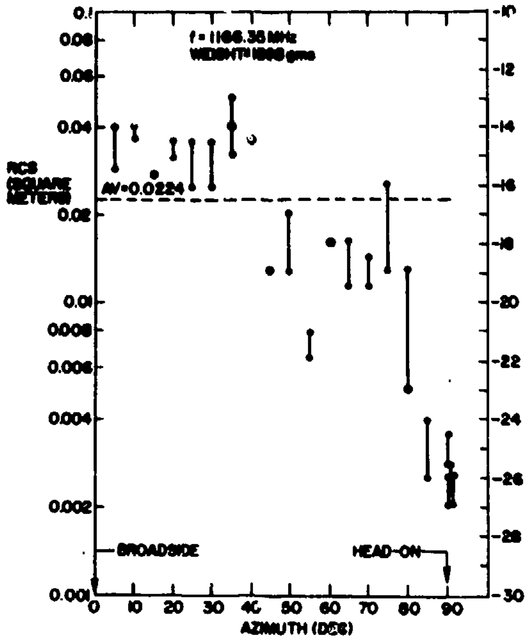
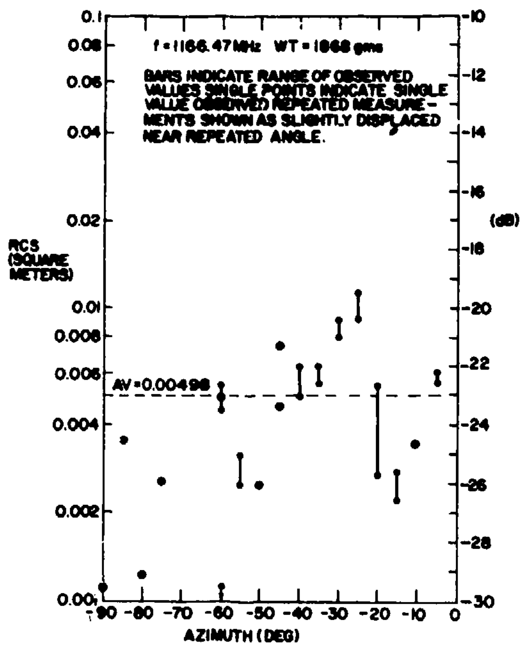
7. Bechtel, M. (1972) Scattering Coefficients for the Backscattering of Electromagnetic Waves from Perfectly Conducting Spheres, CAL Rpt. No. AP/RIS-1, Cornell Aeronautical Laboratory, Inc., Buffalo, NY.

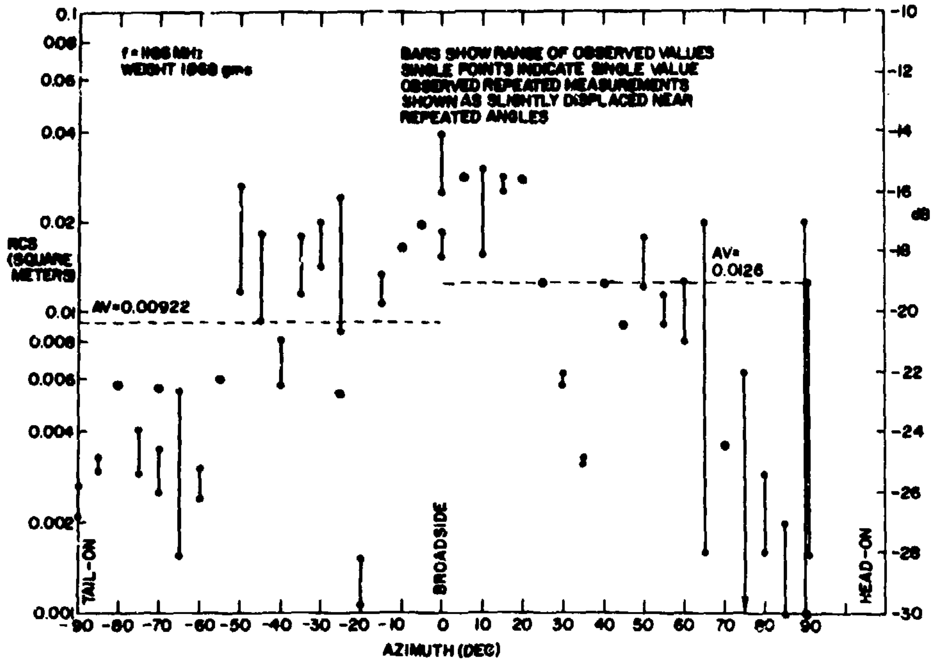


a. Trial 1



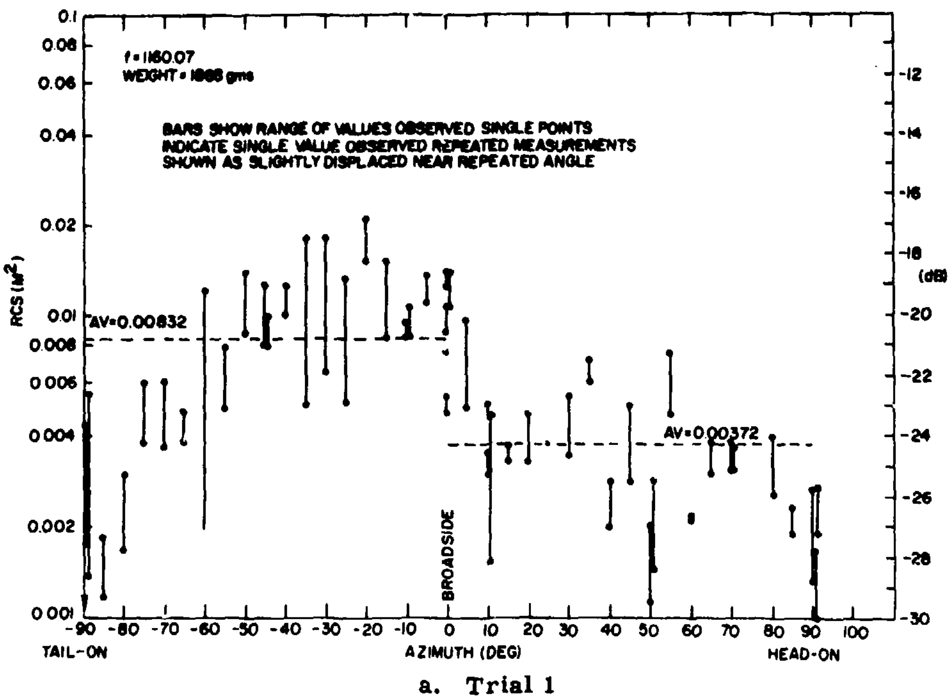
b. Trial 2

Figure 8. Measured Radar Cross Section — Duck No. 2, Horizontal Polarization



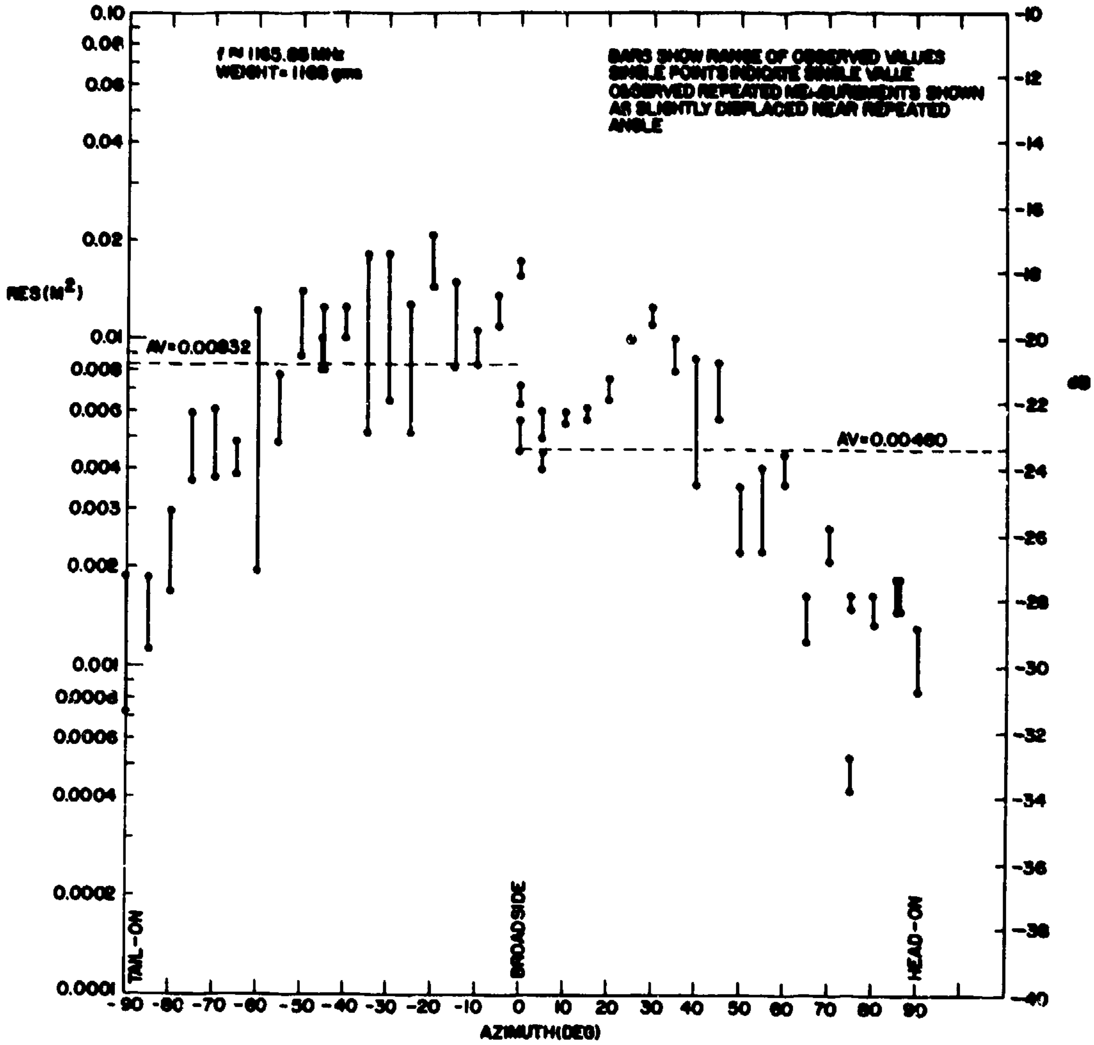
c. Trial 3

Figure 8. Measured Radar Cross Section – Duck No. 2, Horizontal Polarization (Cont.)



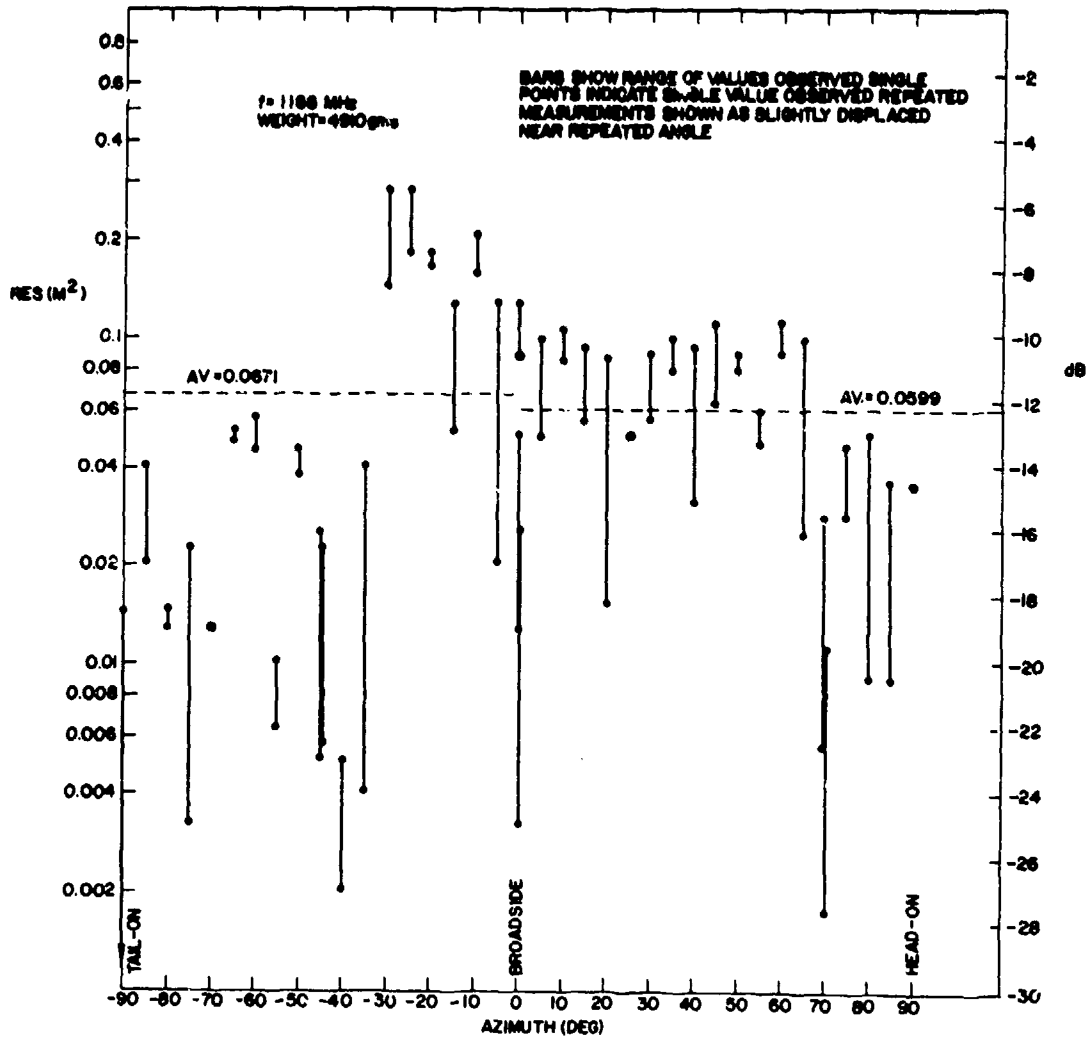
a. Trial 1

Figure 9. Measured Radar Cross Section – Duck No. 2, Vertical Polarization



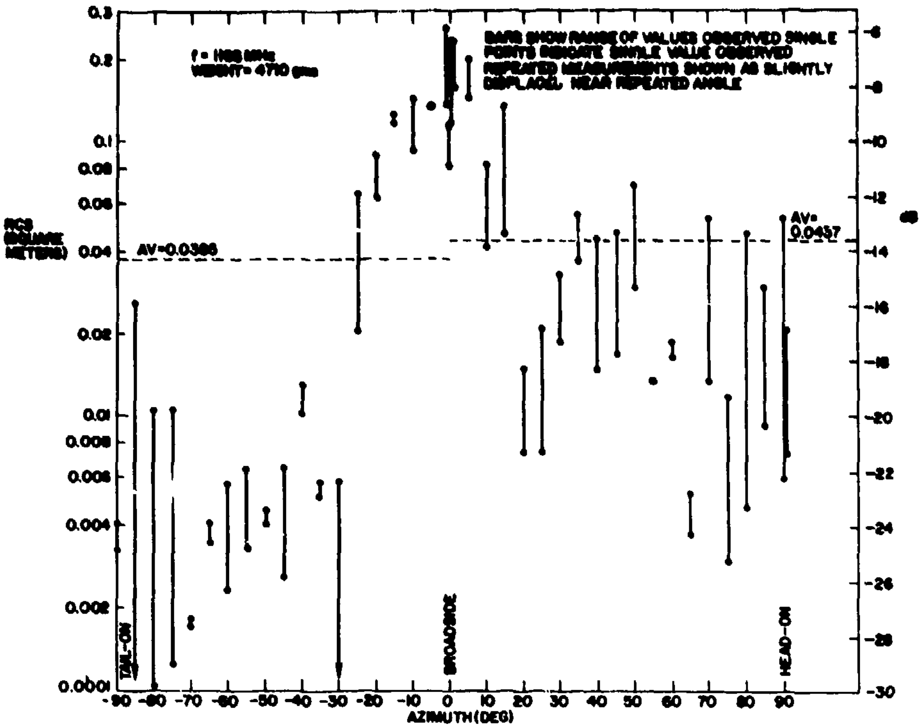
b. Trial 2

Figure 9. Measured Radar Cross Section — Duck No. 2, Vertical Polarization (Cont.)



a. Trial 1

Figure 10. Measured Radar Cross Section – Goose, Horizontal Polarization



b. Trial 2

Figure 10. Measured Radar Cross Section — Goose, Horizontal Polarization (Cont.)

Repeated measurements at a given angle are shown in the figures as slightly displaced at that angle.

An average value of the cross section in square meters for each quadrant and each set of measurements is also given in Figures 7 to 11. This average was calculated by first averaging the range of observed values at each angle and then the results of repeated measurements at each angle. Then the resulting single value at each angle in the measurement set were averaged to yield the number given.

The procedure used in making the measurements was to place the bird in its cage on the mount and wait a short time, 5 to 10 sec, for the bird to readjust itself. This commonly was a period of wild fluctuations of the signal, although the birds tended to move less after they become familiar with the procedure. After this initial period, the signal typically varied much less, indicating less movement by the bird. The signal was observed for the next 10 to 15 sec and its maximum and minimum values recorded. As can be seen from the repeated measurements, the range of signal variation from measurement to measurement changed radically, even with the same bird and same azimuth orientation. Not much data were taken

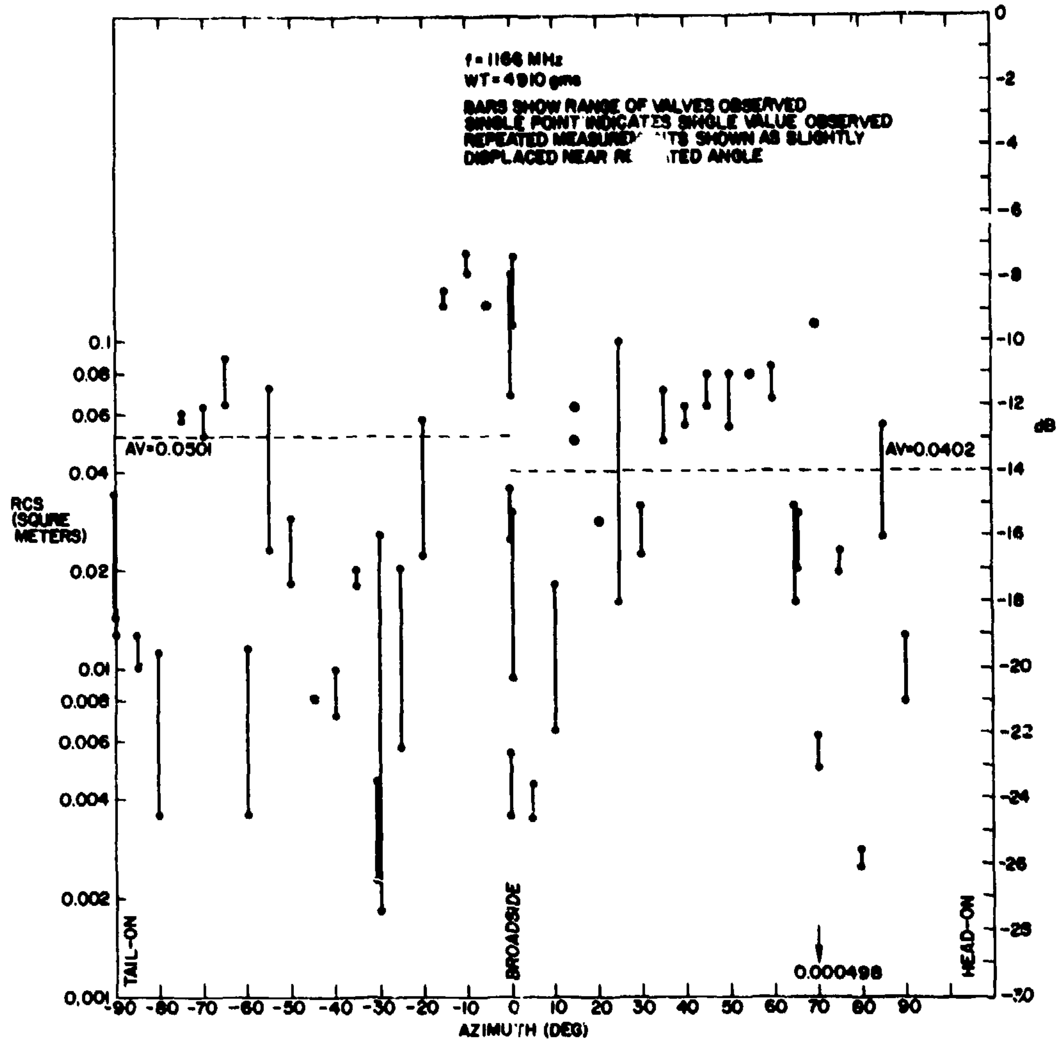


Figure 11. Measured Radar Cross Section — Goose, Vertical Polarization

with duck No. 1 because it was especially fractious and nervous, and frequently tried to stretch during the measurements. The second duck and the goose were much more relaxed and quiet. In fact, the goose was by far the easiest to work with, even though much heavier than the ducks.

When in their cage on the mount, the ducks generally squatted with their neck curved back over the front of their body in a typical nesting attitude, appearing very much as typical duck decoy models. Thus, with either polarization, the measured scattering from the ducks was primarily scattering from their bodies, with some perturbations due to movement of their heads. In an actual radar situation with the birds in flight, the closest equivalent to the measured results would be vertical polarization at any azimuth orientation of the bird, or near head-on or tail-on directions with any polarization.

The goose, on the other hand, tended to stand in the cage with his neck partially extended but at an angle of approximately 45°, so that scattering from the neck significantly affected the returns at both polarizations. Although exact measurements were not possible, the neck was estimated to have been typically 2/3 to 3/4 extended in many of the measurements. The position of the neck had a strong influence on the measured radar cross section, and generally explains the wider fluctuations of scattering from the goose.

Some general characteristics of the measured results can be summarized as follows:

<u>Ducks</u>: Maximum cross sections of about 0.048 m^2 were observed with horizontal polarizations near broadside directions in a number of measurements; the cross sections at horizontal polarization exceeded 0.02 m^2 for a fairly large number of measurements and over an azimuth range of approximately ±45° about broadside. With vertical polarization, the cross sections were approximately 40 percent of those at horizontal polarization, with highest readings near broadside of approximately 0.02 m^2.

While exact physical measurements were not attempted, it is interesting to note that if the bodies of the ducks were assumed to be ellipsoids, the ratio of maximum broadside cross sections at horizontal and vertical polarizations is approximately the same as the ratio of the major to minor axis of the ellipsoid.

Although there are fluctuations and there appears to be some angular lobing structure, the average angular variation in cross sections appears to be at least approximately logarithmic. Note, however, that the rate of decrease from broadside to the head-on direction appears to differ from that of the broadside to the tail-on direction. In Figures 7 to 11, this results in different slopes for a straight line approximation to the angular variation of scattering in the forward and rear quadrants.

An examination of the averaged readings shows that for horizontal polarization, the averages of the forward quadrants are consistently higher than those of the rear quadrants, whereas for vertical polarization this relationship is reversed. The actual numbers are summarized in Table 3 for several measurement sets.

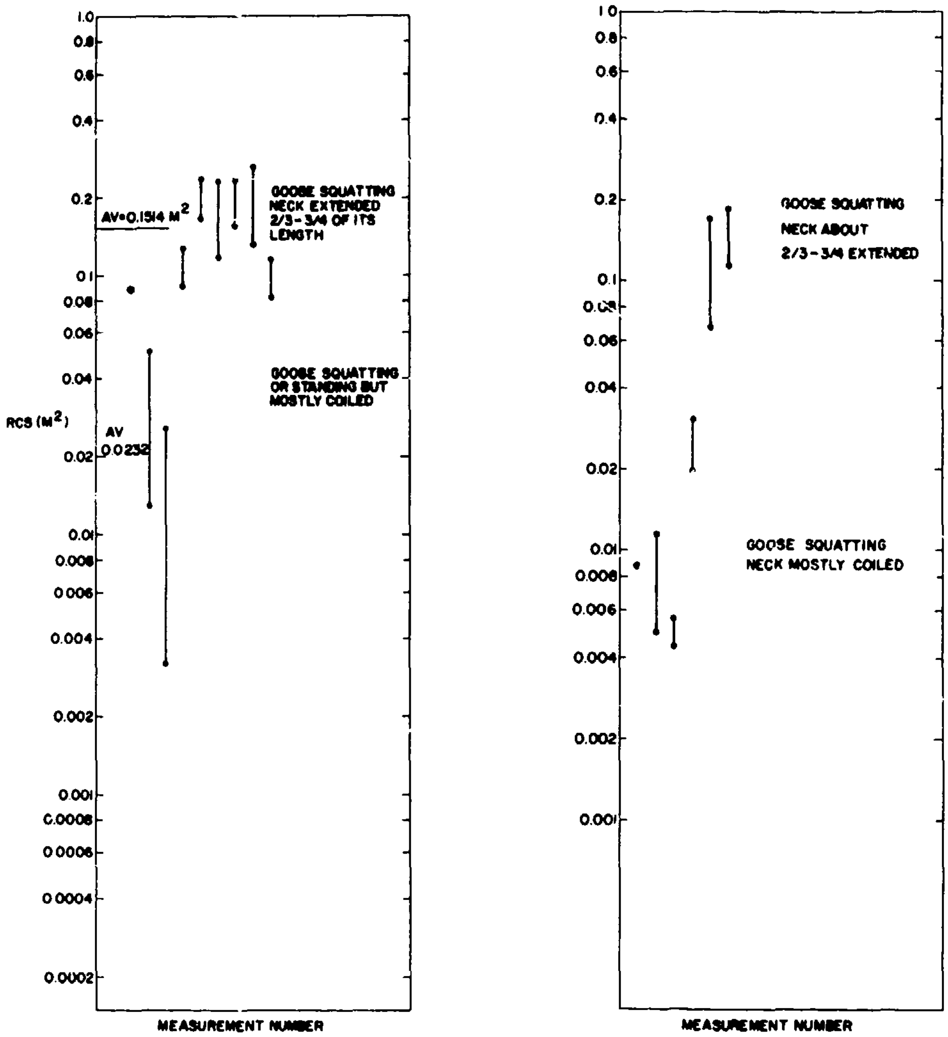
Table 3. Comparison of Averaged Duck Cross Sections

Horizontal Polarization		Vertical Polarization	
Average RCS Front Quadrant	Average RCS Rear Quadrant	Average RCS Front Quadrant	Average RCS Rear Quadrant
0.015 m^2	0.0103 m^2	0.00372 m^2	0.00332 m^2
0.0224 m^2	0.00498 m^2	0.00460 m^2	
0.0126 m^2	0.00922 m^2		

Goose: Again, maximum cross sections were observed with horizontal polarization; these were as large as 0.28 m^2 and remained greater than 0.1 m^2 for a number of measurements and over an azimuth angular interval of at least $\pm 15^{\circ}$ about broadside. At vertical polarization, maximum cross sections were about 0.18 m^2.

Because of the strong influence of the neck, the law of the angular decrease in cross section from broadside to head-on or to tail-on is less evident than for the ducks, and appears to involve an interference relationship between scattering from a thin dielectric cylinder, the neck, and a dielectric ellipsoid, the body. In some cases, it was possible to approximately correlate the position of the goose's neck with repeated measurements at the same azimuth angle. The results of such correlations with the goose at broadside are given in Figure 12. As can be seen from Figure 12, the broadside cross sections are approximately an order of magnitude higher when the neck is nearly extended than when it is coiled back over the body.

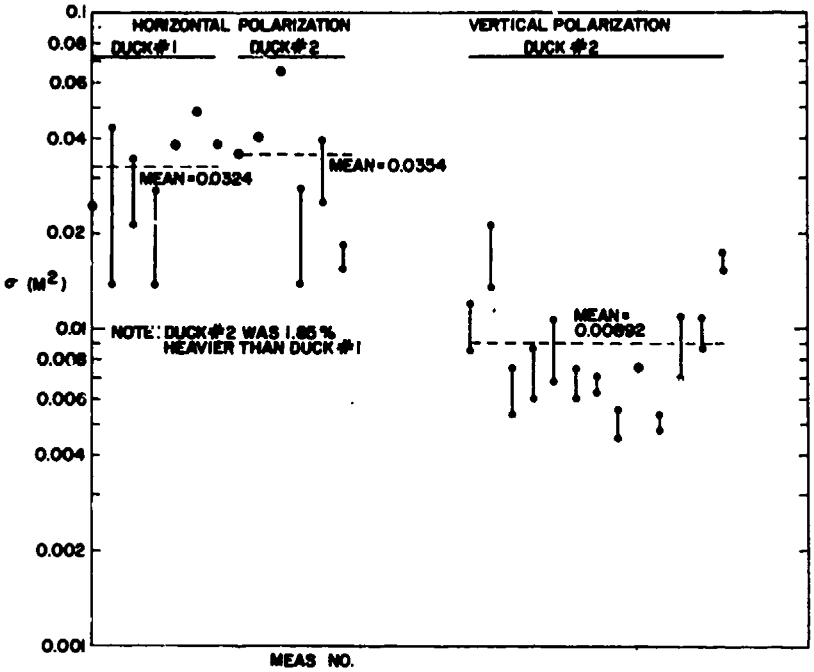
Repeated measurements of the ducks at both polarizations and at broadside, head-on, and tail-on azimuth orientations have been regraphed for easier comparisons in Figure 13. Here, the vertical scale is a cross section in square meters as before, but the horizontal scale is simply the measurement number. Note that the cross section scale in Figure 13c. is one cycle lower to display the lower tail-on cross sections.



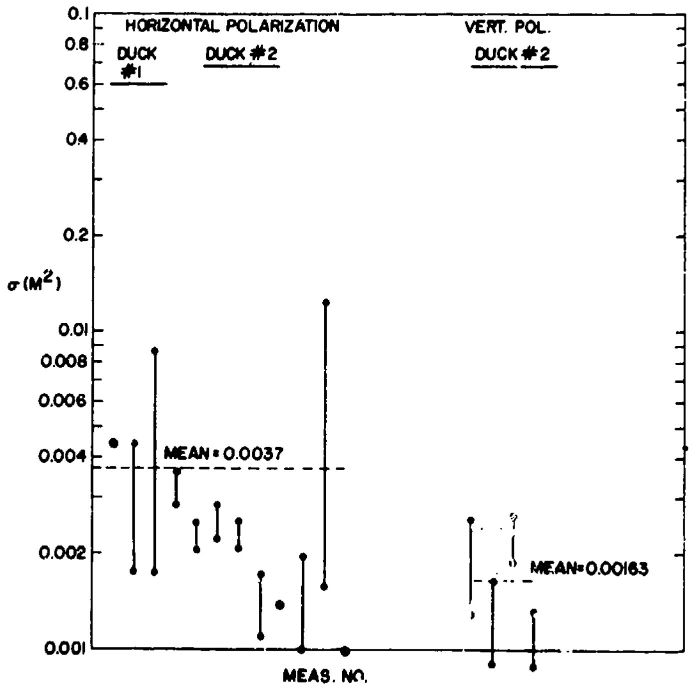
a. Horizontal Polarization

b. Vertical Polarization

Figure 12. Measured Changes in Radar Cross Sections due to Position of Goose's Neck

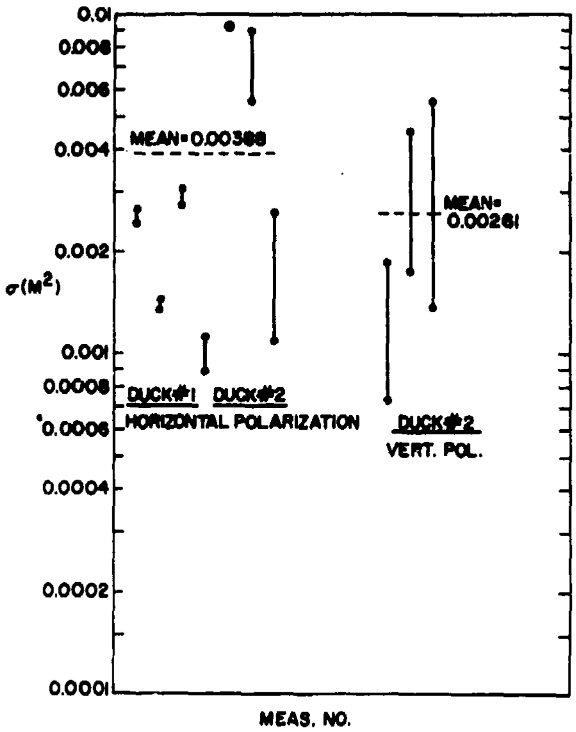


a. Broadside



b. Tail-on

Figure 13. Comparison of Repeated Duck Measurements



c. Head-on

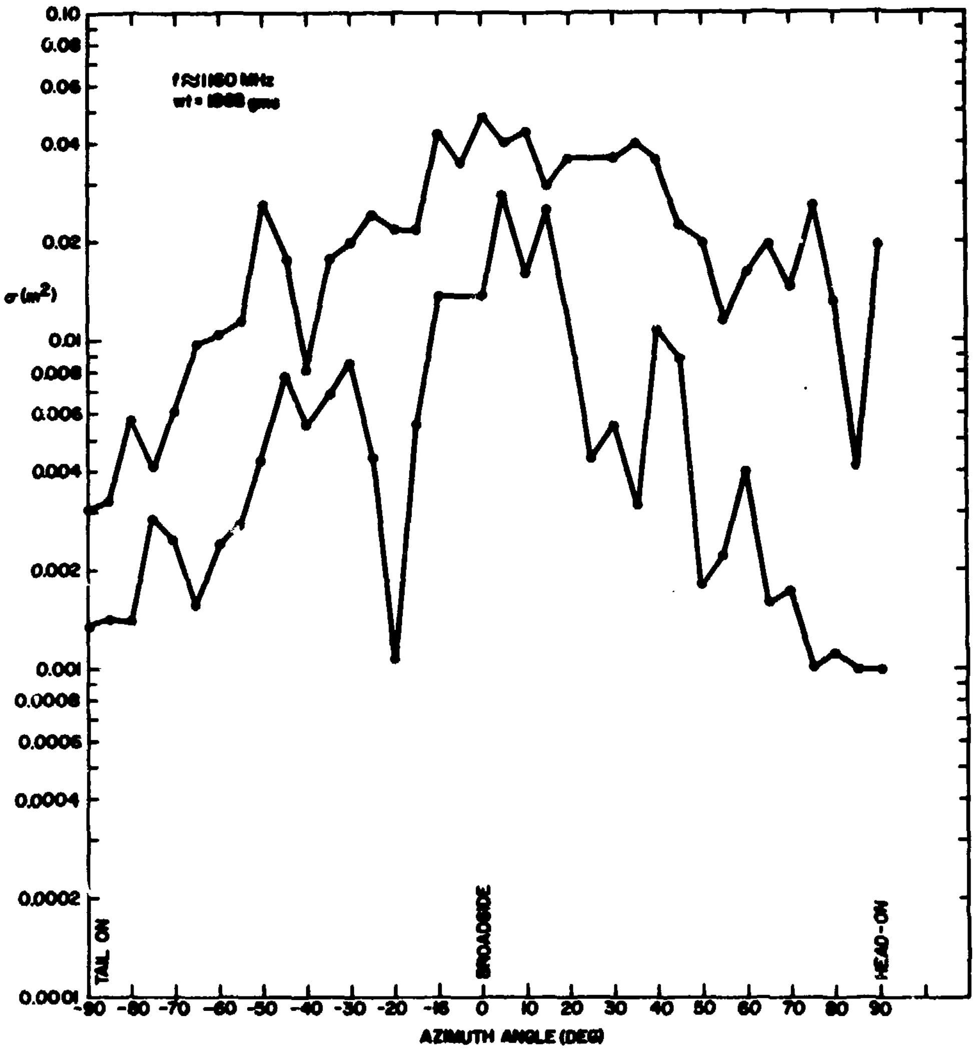
Figure 13. Comparison of Repeated Duck Measurements (Cont.)

4. ANALYSIS OF RESULTS

The fluctuating nature of the individual readings in the basic data of Figures 7 to 11 tends to obscure trends and characteristics that may be present. To aid in identifying such characteristics and trends, the data has been reworked in several ways and the results are presented in this section. Because of the similarity in size and weight of the ducks, their data is combined and treated as repeated measurements of one bird in the following discussions.

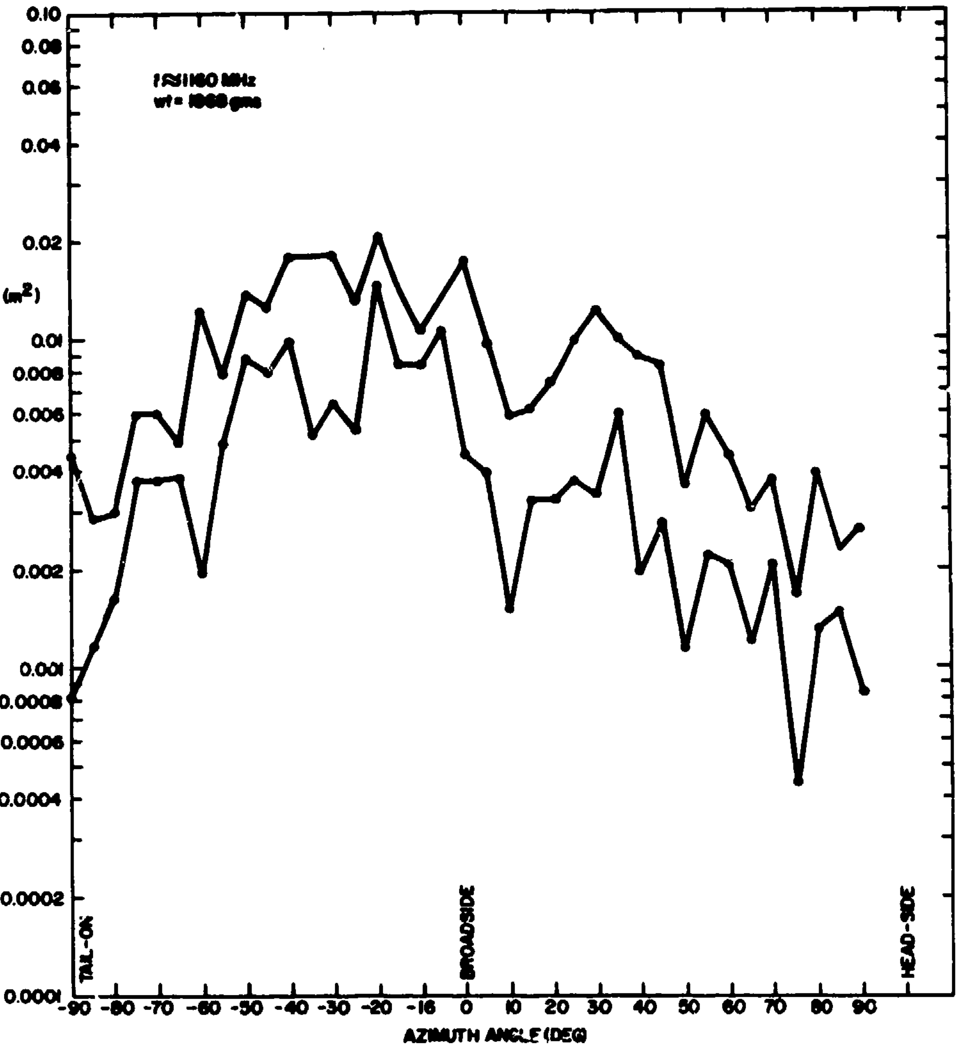
The four parts of Figure 14 show the maximum and minimum cross sections that were obtained with any measurement at a given azimuth angle, polarization, and bird. Thus, all observed values of cross sections lay between the top and bottom curves of each graph of Figure 14; conversely, within the limitations of the number of repeated measurements at many angles, the cross sections of any bird of the same general shape and approximately the same weight should fall within the appropriate pair of lines.

The top line in each part of Figure 14 represents a worst case situation. Cross sections as large as those given by the top line were observed at each angle for each combination of polarization and bird.



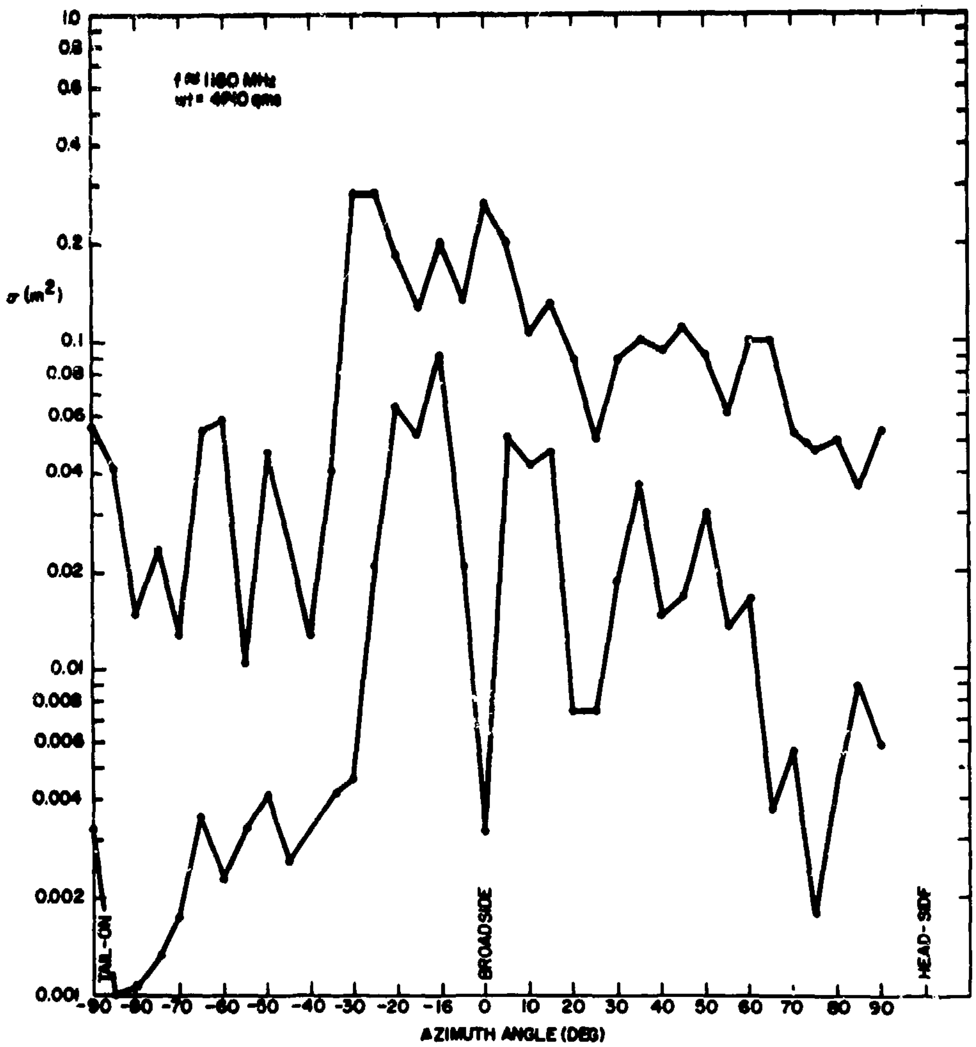
a. Duck, Horizontal Polarization

Figure 14. Maximum and Minimum Measured RCS of Birds



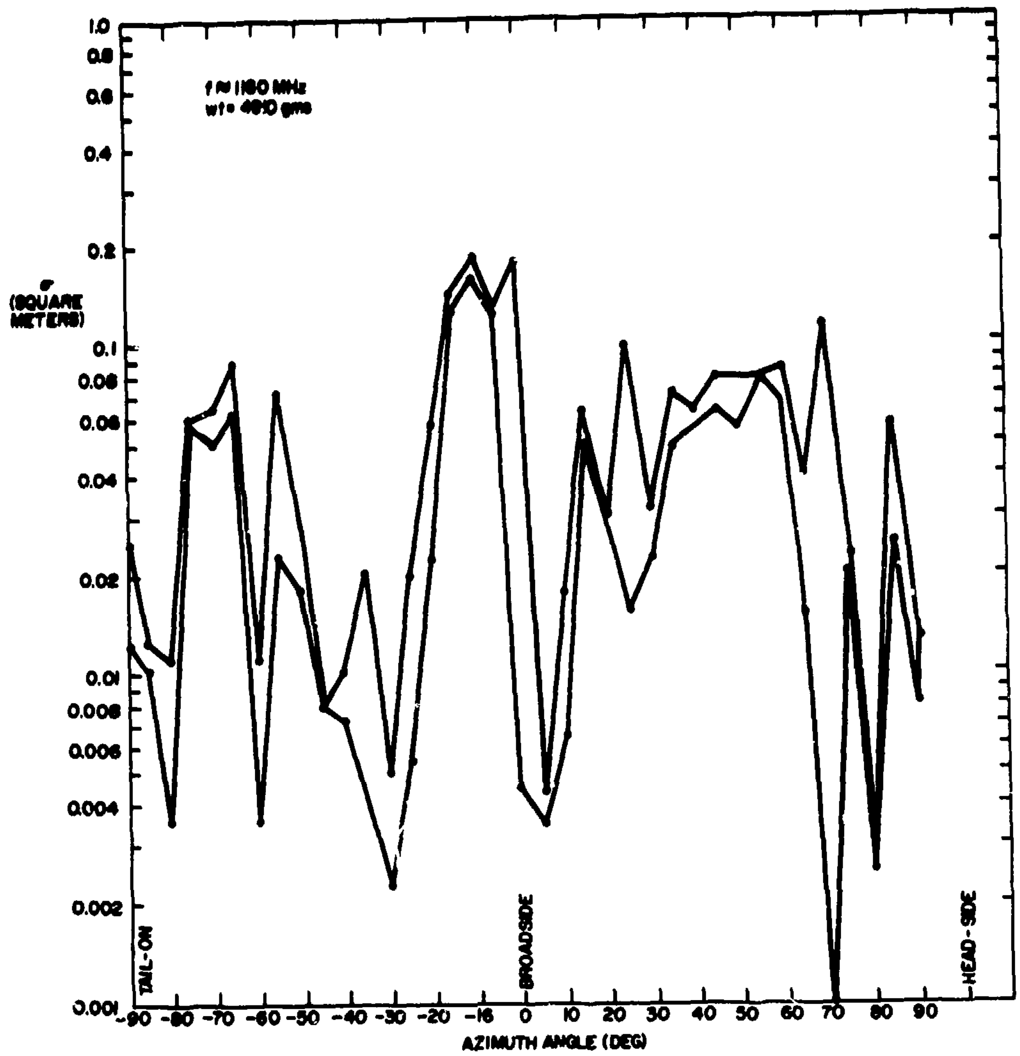
b. Duck, Vertical Polarization

Figure 14. Maximum and Minimum Measured RCS of Birds (Cont.)



c. Goose, Horizontal Polarization

Figure 14. Maximum and Minimum Measured RCS of Birds (Cont.)



d. Goose, Vertical Polarization

Figure 14. Maximum and Minimum Measured RCS of Birds (Cont.)

In general, the bird consists of an assembly of several principal sources of scattering and the top line (of Figure 14) represents the net scattered signal when these different scattering sources are most nearly adding together in phase; the bottom line represents their most out of phase condition.

Generally, the cross section fell somewhere between the two extreme lines. In measurements where the observed variation included one or both of the extreme values, this value was typically repeated a number of times within a time period of about 5 sec. That is, the cycle of variation tended to have a period on the order of 1 or 2 sec or less.

General characteristics of the scattering patterns are more evident in Figure 14, particularly in terms of the maximum cross sections. For example, from Figures 14a and 14b the duck may be seen to have a relatively simple, approximately exponential decrease in cross section from broadside to end-on direction for both polarizations. The strong influence of the goose's neck is evident at vertical polarization in the large variations of maximum cross sections with angle in Figure 14d.

Figure 15 shows a smooth curve fitted to the measured data points of maximum scattering of the duck at horizontal and vertical polarization, curves (a) and (b), respectively. The curve fitting was done by hand, subject to the requirement that the curve and its slope should be continuous and that any points not falling on the curve should be approximately averaged. All points were considered to be of equal validity and accuracy.

Note that the scattering is essentially independent of polarization over an azimuth angular region of approximately $\pm 60^{\circ}$ about the tail-on direction, but the cross section at horizontal polarization is approximately 3 to 4 times that at vertical polarization in the broadside through head-on angular region.

Curve ' Figure 15 for horizontal polarization appears to have principal minimum at averaged values from broadside at $\pm 47.5^{\circ}$ or ± 0.829 rad. At horizontal pol ation, the dominant scattering source will be the body of the duck. Treated as a simple illuminated aperture, this would produce its first principal nulls at $\pm\lambda/D$ radians where D is the effective length of the aperture. Solving for the eff tive scattering length of the duck with a wavelength of approximately 10 in. and first principal nulls at ± 0.829 rad yields D = 12.06 in., which is approximately estimated physical length of the body of the ducks.

Figure 16 contains the same data as Figure 15 but shows a much simpler average curve fit to the data. For both polarizations, all but a few points fall within ± 3 dB of the simple curves. From Figure 16, it is clear that three straight-line segments for each polarization form good average representations of the angular variations of the data over the entire azimuth from tail-on through head-on.

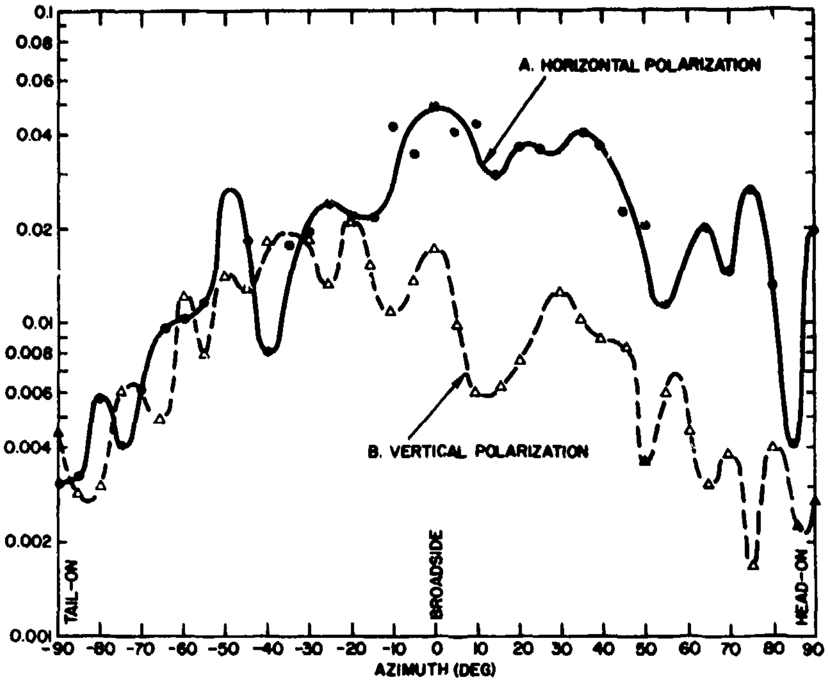
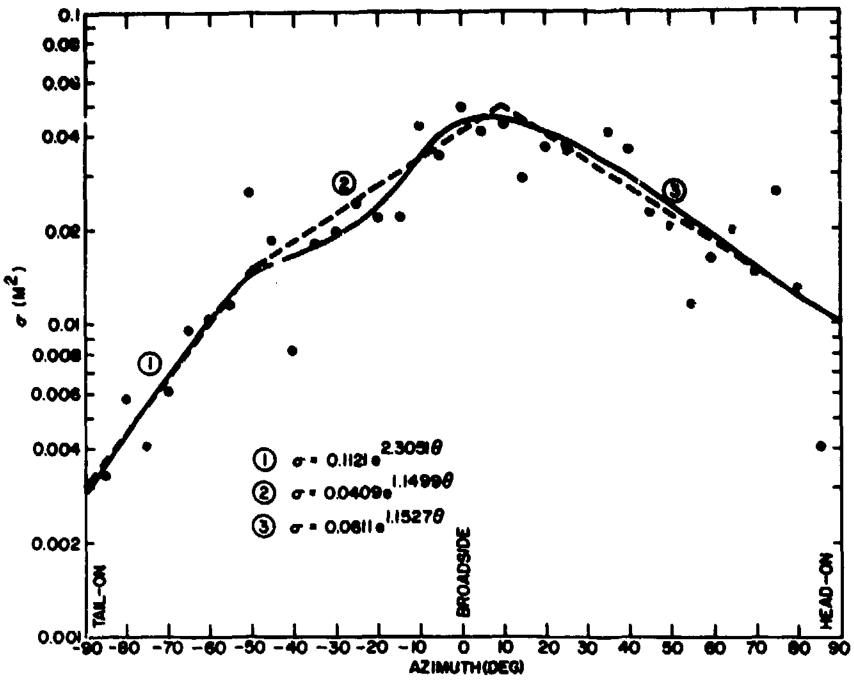


Figure 15. Smooth Curve Fit to Maximum RCS of Ducks, (a) Horizontal Polarization, (b) Vertical Polarization

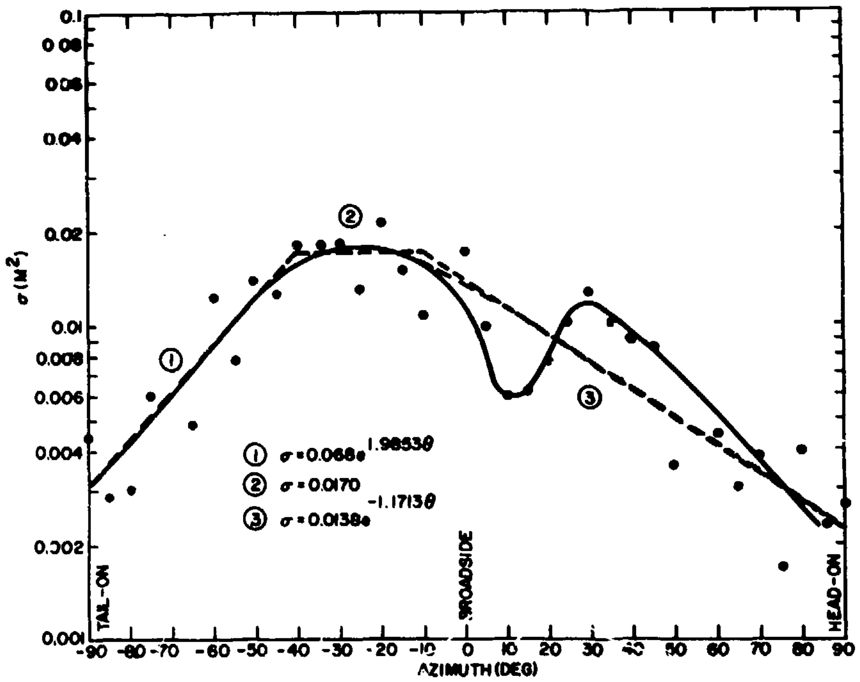
Further, parameters defining the line will be nearly the same for both horizontal and vertical polarization over the interval of about $\pm 45^{\circ}$ about tail-on, and the line segments will have nearly the same slope, although it will be displaced in intercepts for both horizontal and vertical polarization over the azimuth range of approximately $\pm 80^{\circ}$ about the head-on direction. Sets of line segments obtained by inspection are:

<u>Horizontal Polarization</u>:

$-90^{\circ} \leq \theta \leq -50^{\circ}$ $(-\pi/2 \leq \theta \leq -0.8726$	$\text{Log } \sigma = 1.0011\theta - 0.9503$
$-50^{\circ} \leq \theta \leq +10^{\circ}$ $(-0.8726 \leq \theta \leq 0.1745)$	$\text{Log } \sigma = 0.4794\theta - 1.3881$
$10^{\circ} \leq \theta \leq 90^{\circ}$ $(0.1745 \leq \theta \leq \pi/2)$.	$\text{Log } \sigma = 0.5006\theta - 1.2137$



a. Horizontal Polarization



b. Vertical Polarization

Figure 16. Approximate Curve Fit to Maximum RCS of Ducks

Vertical Polarization:

$-90^{\circ} \leq \theta \leq -40^{\circ}$ $\quad$ $\text{Log}\ \sigma = 0.8633\theta - 1.1670$

$(-\pi/2 \leq \theta \leq -0.6981)$

$-40^{\circ} \leq \theta \leq -10^{\circ}$ $\quad$ $\text{Log}\ \sigma = 1.7696$

$(0.6781 \leq \theta \leq -0.1745)$

$-10^{\circ} \leq \theta \leq 90^{\circ}$ $\quad$ $\text{Log}\ \sigma = 0.5087\theta - 1.8585$

$(0.1745 \leq \theta \leq \pi/2)$.

These line segments are shown as dashed lines in Figure 16.

Expressed as exponentials, these line segments give the following cross sections:

Horizontal Polarization:

$-90^{\circ} \leq \theta \leq -50^{\circ}$ $\quad$ $\sigma = 0.1121\ e^{2.3051\theta}$ square meters

$(-\pi/2 \leq \theta \leq -0.8726)$

$-50^{\circ} \leq \theta \leq +10^{\circ}$ $\quad$ $\sigma = 0.0409\ e^{1.1497\theta}$

$(-0.8726 \leq \theta \leq 0.1745)$

$10^{\circ} \leq \theta \leq 90^{\circ}$ $\quad$ $\sigma = 0.0611\ e^{-1.1527\theta}$

$(0.1745 \leq \theta \leq \pi/2)$.

Vertical Polarization:

$-90^{\circ} \leq \theta \leq -40^{\circ}$ $\quad$ $\sigma = 0.0681\ e^{1.9053\theta}$

$(-\pi/2 \leq \theta \leq -0.6981)$

$-40^{\circ} \leq \theta \leq -10^{\circ}$ $\quad$ $\sigma = 0.0170$

$(-0.6981 \leq \theta \leq -0.1745)$

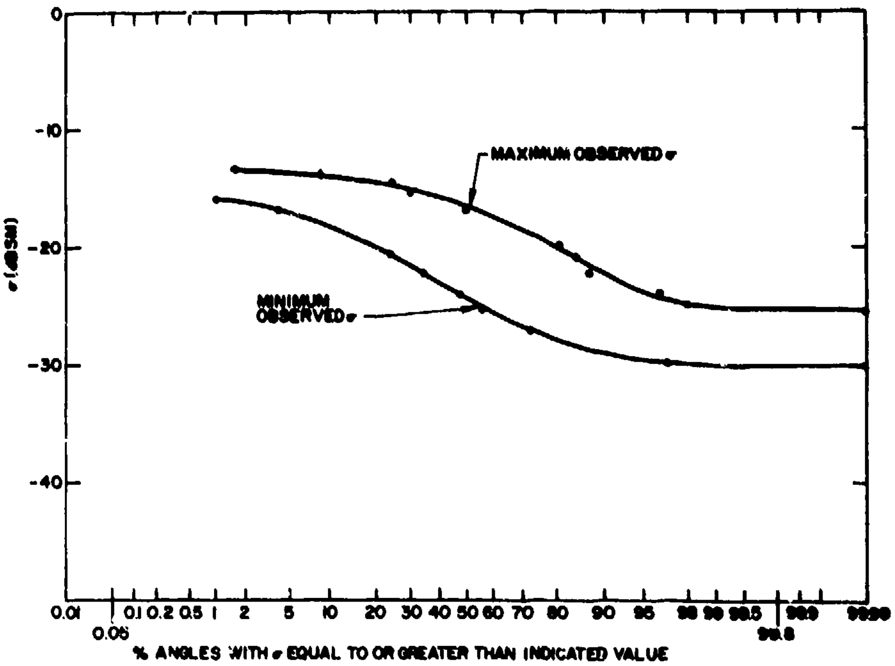
$-10^{\circ} \leq \theta \leq 90^{\circ}$ $\quad$ $\sigma = 0.013\theta\ e^{-1.1713\theta}$

$(-0.1745 \leq \theta \leq \pi/2)$.

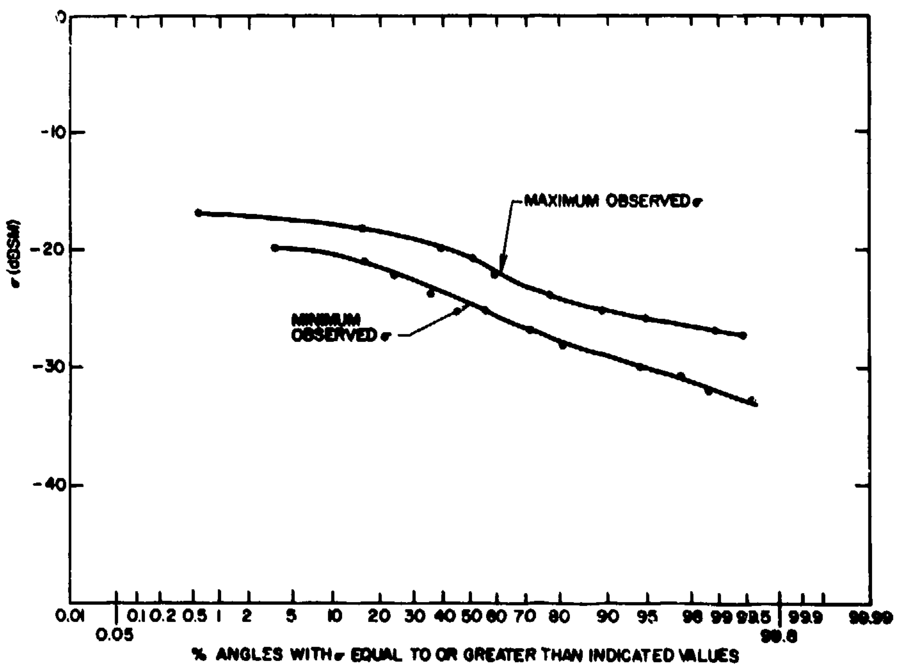
Similar curve fitting was not carried out with the data for the goose, because its scattering pattern appears to be the result of a more complicated set of interferring scattering centers.

Cumulative probability curves for the maximum and minimum values of observed cross sections are given in Figure 17. The curves of Figure 17 were derived from those of Figure 14 by calculating the percentage of observation angles for which the measured cross sections equaled or exceeded the indicated levels, referred to one square meter. Again, the curves of maximum cross section represent a worst-case situation.

If there is assumed to be an equal probability of observing the bird at each azimuth angle and the percentage of observation angles is divided by 100, the

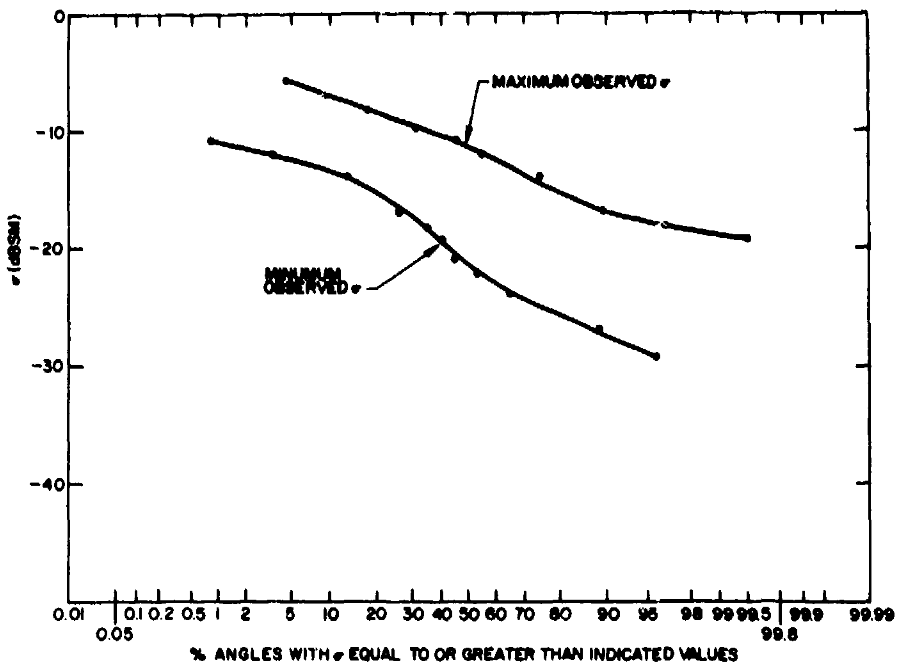


a. Horizontal Polarization, Ducks

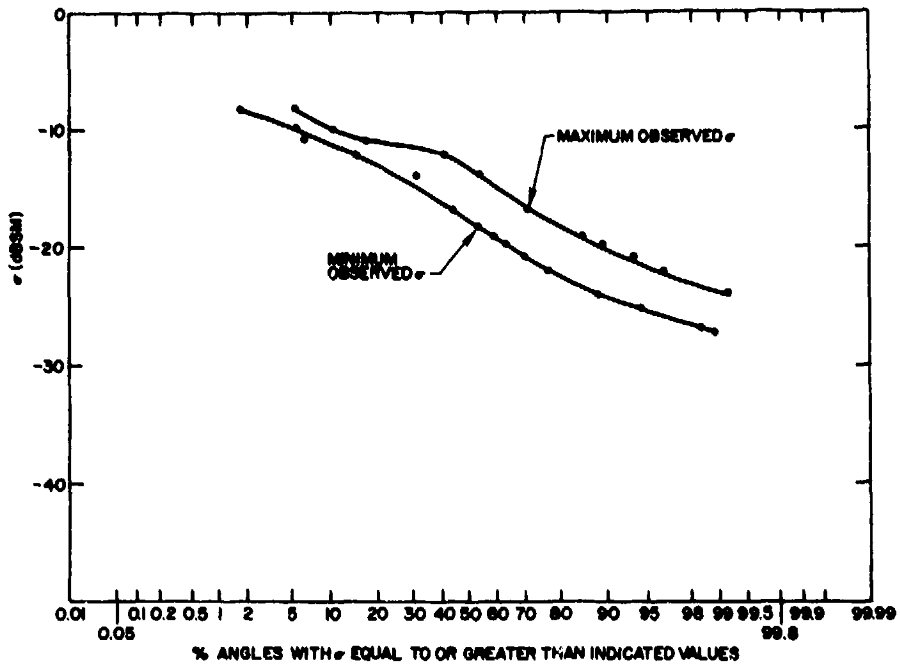


b. Vertical Polarization, Ducks

Figure 17. Cumulative Probability, Maximum and Minimum RCS



c. Horizontal Polarization, Goose



d. Vertical Polarization, Goose

Figure 17. Cumulative Probability, Maximum and Minimum RCS (Cont.)

curves of Figure 17 become the probability of observing the bird when its cross section equals or exceeds the indicated level.

From Figure 17a., for example, the maximum measured cross section of the duck at horizontal polarization equalled or exceeded -16 dB m^2, or 1/40 m^2, over 43 percent of its azimuth angles, or over 155° of its 360°. Maximum cross sections equalled or exceeded -20 dB m^2 or 1/100 m^2 over 80 percent or 288 of its 360 azimuth degrees, and maximum cross sections exceeded -25.5 dB m^2 over all azimuth angles. In terms of probability, there is an 0.8 probability of observing the duck at L-Band with horizontal polarization when its maximum cross section exceeds 1/100 m^2, and a 0.9999 probability of observing the duck when its maximum cross section exceeds -25.5 dB m^2.

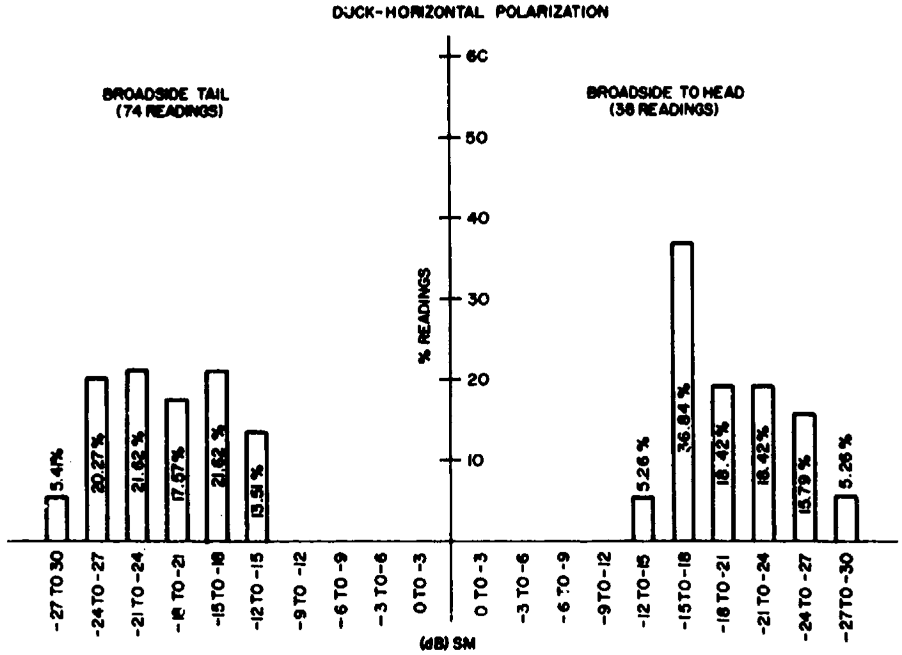
The maximum cross sections will, of course, not necessarily be observed every time and generally will not be observed continuously during a period of observation. Therefore, the probability of observing the maximum cross section will be somewhat less than indicated by the simple argument preceding. For example, if the maximum cross sections were observed in 50 percent of the measurements, the probability of observing it would be cut in half.

However, cross sections that were measured all equalled or exceeded the bottom curves of Figure 17. Hence, from Figure 17a., if the bird is observed, there is a 20 percent probability that the observed cross section will exceed -20 dB m^2 and perhaps a 10 percent probability that it will exceed -14 dB m^2. There is a probability of 100 percent that if the bird is observed with horizontal polarization its cross section will exceed -30 dB m^2.

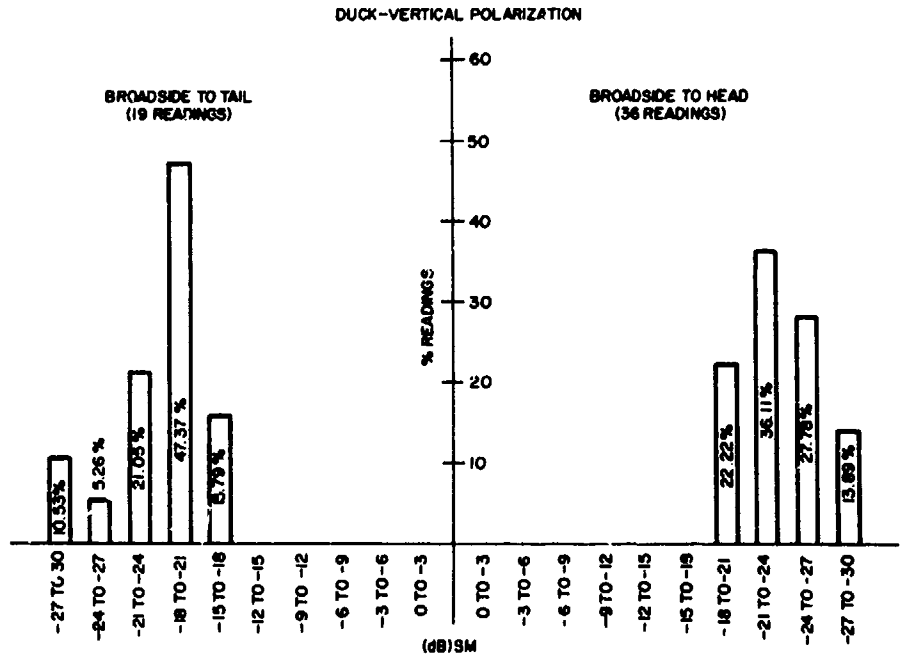
At vertical polarization the values of Figure 17b. are somewhat lower, but there is a probability of 1.0 that if observed with vertical polarization the duck's cross section will exceed -33 dB m^2.

For the goose, Figure 17c. and d., the values are considerably higher. With horizontal polarization the maximum cross sections exceeded -10 dB m^2 or 0.1 m^2 over 34 percent of the angles, and the maximum cross section always exceeded -19.5 dB m^2 or 1/100 m^2. The curve of minimum cross, for example, exceeded -20 dB m^2 over 42 percent of the azimuth and -25 dB m^2 over 75 percent of the azimuth. At vertical polarization the values were a little higher with the curve of minimum cross section equalling or exceeding -20 dB m^2 over 63 percent of the azimuth direction's and -27 dB m^2 over 97 percent of the directions.

Figure 18 shows the distribution of all of the measurements for each bird at each polarization. The forward and rear quadrants are shown separately in each case. The bar graphs of Figure 18 were constructed by creating the 3 dB boxes, counting the number of measurements that fell into each box, and dividing the total of each box by the total number of measurements. When a measurement covered

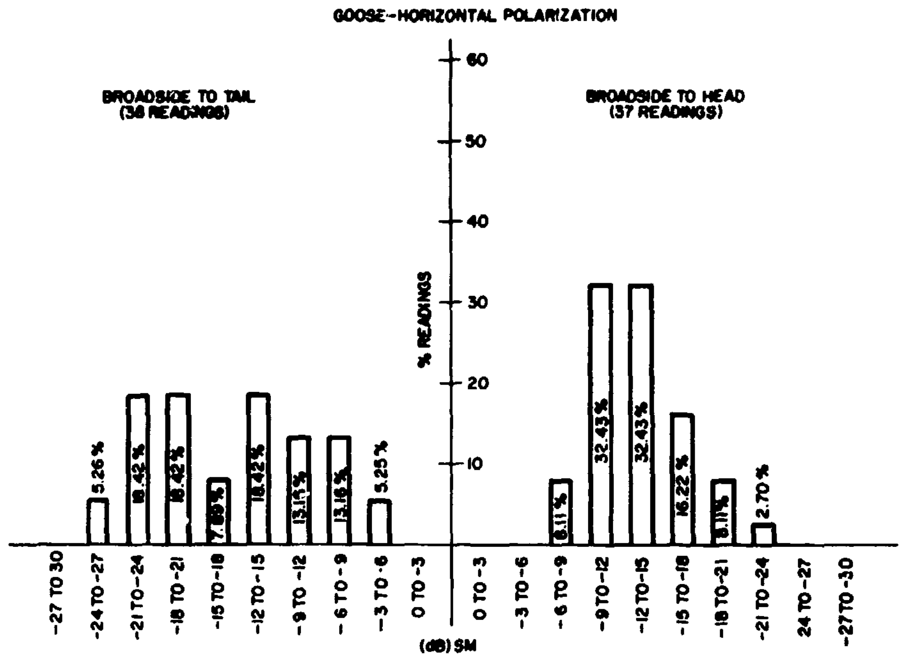


a. Duck Horizontal Polarization

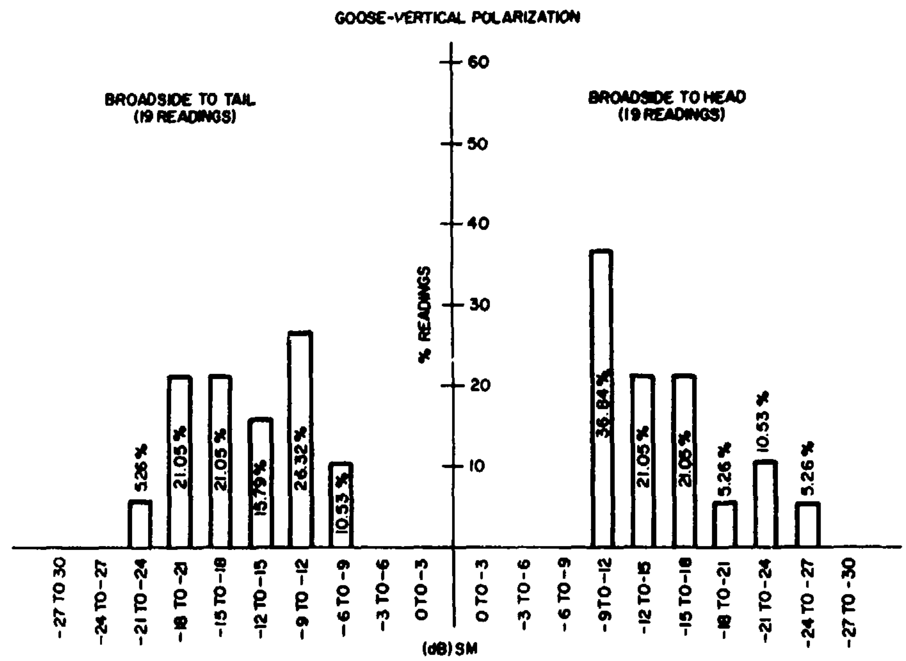


b. Duck Vertical Polarization

Figure 18. Distribution of Measured Cross Sections



c. Goose Horizontal Polarization



d. Goose Vertical Polarization

Figure 18. Distribution of Measured Cross Sections (Cont.)

a range of values, the measurement was counted in the box that contained the maximum of the range. Repeated measurements were combined to weigh each angle equally.

Measurements in the forward quadrant from broadside to head-on tend to be distributed approximately the same for both birds and at both polarizations. In the rear quadrant, however, the measurements at horizontal polarization tend to be roughly evenly distributed over the entire range of cross sections. At vertical polarization, measurements of the duck in the region from broadside to tail-on tend to be tightly grouped about a narrow range of cross sections. For example, 47.4 percent of the measurements fell into the 3 dB range of -18 to -21 dB m^2. However, this result was based on only one set of measurements of this quadrant at vertical polarization. Similarly, results for the goose in this rear quadrant are more tightly grouped at vertical polarization than at horizontal polarization, but the difference is not as striking as for the duck. For the goose, only one set of measurements was obtained over the rear quadrant at vertical polarization.

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